MR Aug. 1943

A-70

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

August 1943 as
Memorandum Report

ELIMINATION OF RUMBLE FROM THE COOLING DUCTS OF A SINGLE-ENGINE PURSUIT AIRPLANE

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Moffett Field, California

NACA

WASHINGTON

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Materiel Command, U.S. Army Air Forces

ELIMINATION OF RUMBLE FROM THE COOLING DUCTS OF A SINGLE-ENGINE PURSUIT AIRPLANE

By Howard F. Matthews

SUMMARY

A full-size single-engine pursuit airplane, with wing tips cut off, was tested in the 16-foot wind tunnel of the Ames Aeronautical Laboratory at Moffett Field, Calif. The purpose was to find means for eliminating an extreme rumble which occurred at high speeds when the radiator air-duct-exit openings were small.

The most effective remedy found was placing the entrance to the duct well out of the boundary layer of the wing so that the velocity distribution would be favorable toward removal of separation and buffeting in the duct. Increasing the depth of the gutter and reducing the inlet area may also have contributed to correction of the defect.

INTRODUCTION

Pilots of the airplane had reported that a heavy vibration or a rumble occurred at high speed, apparently in the radiator air ducts. The severity of the rumble was said to be increased, mainly, by closing the flap at the exit of the coolant-radiator duct and, to a lesser extent, by closing the flap of the oil-radiator duct. In addition, it appeared that the rumble was more severe at angles of attack less than required for high-speed level flight.

Preliminary work done in flight by the manufacturer indicated that the rumble was not caused, primarily, by vibration of the duct structure itself. The noise was so severe, however, that some remedy was necessary. Therefore, at the request of the Army air Forces, Materiel Command, an investigation of the problem was undertaken in the 16-foot wind tunnel of the Ames Aeronautical Laboratory, for it was realized that considerable time could be saved by utilizing a wind tunnel, rather than free flight, in the test program.

WIND TUNNEL AND TEST AIRPLANE

The 16-foot wind tunnel of the Ames Aeronautical Laboratory has a closed test section, a single closed return passage, and is of circular cross section throughout.

The airplane furnished for the wind-tunnel tests differed from the production model in that the wing was placed 3 inches higher. This variation resulted in the carburetor scoop being below the bottom of the wing, but the effect on the cooling air-duct performance was thought to be negligible.

In order to mount the airplane in the wind tunnel, the wing tips were cut off and fittings were secured to the wing spars for attachment to the trunnion plates. In addition, the empennage and propeller were removed, a spinner was installed to fair the nose of the fuselage, and a fairing was fitted over the tail end.

TEST METHOD

For tests at speeds up to 260 miles per hour, the airplane was supported only on the trunnion plates (fig. 1). The angle of attack was varied by rotating the trunnion plates, and the forces on the airplane were measured by the self-balancing, recording beam scales of the regular balance system.

For the high-speed tests, the airplane was given additional support by a tail strut (fig. 2) which was securely fastened to the top of the tunnel shell. Force measurements were not made for this type of mounting.

A pilot, or occupant, of the airplane was essential, since the rumble could be distinguished only from inside the cockpit. Communication was maintained with the pilot through earphones and throat microphones.

The program for tests was completely flexible and depended largely upon what was learned as the investigation proceeded. In general, for each change in form or arrangement of the duct, the exit openings were varied through electrical control of the flaps by the pilot, who also observed the rumble. The flap openings employed, as measured at the center, and the corresponding areas at the exits were as follows:

Coolant-radiator duct		Oil-radiator duct	
Flap opening (in.)	Area (sq ft)	Flap opening (in.)	Area (sq ft)
1.3	0.14	0.6	0.04
5.9	.80	3.1	.22
10.3	1.43	8.0	.58
14.5	2.13	---	---

The smallest openings given above were for the flaps against the stops and provided the minimum area available. The openings of 5.9 inches and 3.1 inches for the coolant-radiator duct and oil-radiator duct, respectively, were for flaps flush with the outer surface of the duct. The largest openings were the maximum available.

The choice of modifications investigated was influenced greatly by the comments of the pilot regarding the rumble and by visual observation of the air flow about the duct through the aid of wool tufts. Photographs of the tufts were made to obtain records of the air flow in typical cases. If the modification under test indicated a decrease of the rumble, pressure data for computing the flow through the ducts were recorded and drag tests at three angles of attack were made.

The data were corrected, approximately, for the rather large constriction effects on the dynamic pressure, velocity, density, and Mach number, but not for the tunnel-wall effects on the angle of attack.

The dynamic pressure of the air flowing through the duct was measured by pitot tubes placed at the entrance for the two successful designs, and by a number of total-pressure tubes and static-pressure orifices aft of the radiators in the case of the original duct. The accuracy of the dynamic-pressure measurements for the original duct is questionable, as the data are for a low-speed section. The temperature was measured at the large end of the wind-tunnel entrance cone and was computed for points in the duct by assuming adiabatic expansion. From these measurements, the density, velocity, and mass flow of air in the ducts were computed.

For computing the drag coefficient C_D, the total airplane wing area of 233.19 square feet was used.

RESULTS AND DISCUSSION

Rumble.- Before the investigation of the problem could be initiated, the rumble had to be obtained in the wind tunnel. By trial, it was found to be very severe at the geometrical angle of attack corresponding to an angle of inclination for the fuselage reference line of -2°. (The angle of the fuselage reference line with respect to the wind direction is hereafter designated as angle of attack α.)

The preliminary tests, with a pilot in the cockpit and a passenger in the aft portion of the fuselage, disclosed that the main contribution to the rumble was the vibration of the coolant radiator, evidently caused by pulsations in the flow through the duct.

Since the rumble did not occur when the coolant-duct-exit opening was large, the first modification was to provide an increase in the minimum value of the entrance velocity relative to the free-stream velocity. A bypass arrangement, shown in figure 3, was designed to achieve this purpose. The results were encouraging in that, with the bypass louvers at the most effective opening, the velocity at which the rumble began was raised approximately 150 miles per hour.

A study of the tufts (figs. 4 and 5) indicated that the bottom of the wing near the duct was in a stalled condition and that the flow along the inside of the duct at the top of the entrance was reversed. The upper lip of the entrance was extended 13-3/4 inches ahead of its original position and was faired into the original lower lip. The leading edge of the extension was made straight at the top and was placed about five-eighths of an inch away from the wing-bolt fairing at the center line of the airplane. The extension was faired into the lines of the original duct. The lip extension and the resulting improvement in the flow are shown in figure 6. With the bypass open, the duct, thus modified, had only a slight rumble at 429 miles per hour.

The next modification of duct tried was one conforming to loft lines designed by the manufacturer to provide a higher entrance velocity and to reduce the separation at the top portion leading to the coolant radiator. This was accomplished by extending the partition between the coolant- and oil-radiator ducts to the entrance, and redesigning the coolant-duct diffuser. A flap was incorporated by the Ames Aeronautical Laboratory to provide a bypass from forward of the coolant radiator to aft of the oil radiator. This revision, shown by figure 7, is called the "divided duct." It proved to have a later and less intense rumble than the original, but was inferior to the original as modified by an extended upper lip at the entrance. As before, the bypass removed the rumble to a degree (up to 337 miles per hour) but did not eliminate it at the higher speeds.

Another lip extension was made (fig. 8) and attached to the divided duct. This extension was similar to that used on the original duct, with the exception that it was carried only 10-7/8 inches forward and the leading edge was placed 1 inch away from the wing-bolt fairing. This modification reduced the rumble to a point where it was not discernible from the general vibration of the airplane at 500 miles per hour, the highest speed attained in the tests.

An alternate change was made in the divided duct to determine if placing the entrance farther from the lower surface of the wing or extending the upper lip forward was the more important factor in removing the rumble. The top of the entrance, without lip extension, was lowered about 1 inch farther from the wing surface, and this drop was carried along the top inner surface of the coolant duct to within a few inches of the radiator. From this point, it was faired into the previous lines. The oil-radiator duct was left unchanged. Figure 9 shows this modification. This form, like the divided duct with the extended lip, did not rumble at 500 miles per hour even with both duct-exit flaps closed and the airplane at an angle of attack of -2°.

Cooling air.- The mass flow through the oil-radiator duct for the original design, and for the two that were successful in eliminating the rumble, is shown in figures 10 to 14. The curves indicate that either of the latter (the divided duct with lip extension or the modified divided duct) are satisfactory for cooling the oil. The most noticeable difference among the three is the greater scatter of the curves with changes in coolant-duct flap setting for the original design. This difference may be explained as an effect of the partition between the coolant- and oil-radiator ducts in the divided duct design. The partition, being extended to the entrance, might be expected to reduce the effect of coolant-duct flap setting on the flow through the oil radiator.

Likewise, figures 15 to 19 show the mass flow through the coolant-radiator duct for these three designs. In general, the flow for the original design was slightly greater than for the other two. The curves for the divided duct with the upper-lip extension and for the modified divided duct are much alike, with the exception that at the fully closed position of the coolant-duct-exit flap, those for the modified form show a definitely smaller mass flow.

Drag.- The drag increment, due to substitution of the divided duct for the original duct with lip extension, is shown in figures 20 and 21. In the dive attitude (approximate angle of attack of -2°), either divided duct produced a decrease in the drag coefficient with the coolant-duct flap closed, and only a slight increase (about 0.0002) with the flap flush. At the high-speed level-flight attitude (angle of attack 0°), the drag coefficient was increased an average of about 0.0004. For an angle of attack of 5°, the drag increment was slightly higher.

Figure 22 shows the density, velocity, and Mach number at the position of the airplane and as corrected for constriction effects, as functions of dynamic pressure.

Tables I to IV are a summary of the temperature, density, static pressure, and mass flow at the entrance for the two divided duct designs.

Figure 23 shows the principal forms of duct investigated and gives a summary of the performance, where determined, for the various conditions of the tests.

CONCLUSIONS

The problem of eliminating a heavy vibration or rumble, which occurred at high speeds when the radiator-duct-exit openings were small, was solved by either of two designs.

The first included an upper-lip extension of the entrance to a divided duct, which differed from the original in that the partition between the coolant- and oil-radiator duct diffusers was extended to the entrance. The coolant-duct diffuser was also revised. The effect of the extension was twofold: first, to move the entrance farther from the lower surface of the wing and, second, to increase the depth of the gutter.

The second successful design was a modification of the divided duct. It likewise moved the entrance to the coolant duct away from the lower surface of the wing, but it did not change the depth of the gutter. The revision reduced the inlet area of the coolant duct from 163 square inches to 138.7 square inches.

The more important factor in the solution was evidently placing the entrance of the duct well out of the boundary layer of the wing, so that the velocity distribution at the entrance would be favorable to removal of separation and buffeting in the duct. Increase in the depth of gutter and reduction of inlet area may also have contributed to the solution of the problem.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif.

TABLE I

DIVIDED DUCT WITH LIP EXTENSION-COOLANT RADIATOR DUCT ENTRANCE CONDITIONS

AREA = 163 SQ. IN.

α (°)	q (lbs/ft.²)	Flap Opening (inches) Oil	Flap Opening (inches) Coolant	T (°abs.)	P_{static} (lbs./ft.²)	ρ (slugs/ft.³ ×10⁻⁶)	m (slugs/sec.)
-2	127	8.0	1.3	527	2068	2289	.308
			5.9	536	2063	2246	.487
			10.3	533	2032	2223	.676
			14.5	531	1999	2195	.797
	254		1.3	540	2015	2176	.430
			5.9	539	2002	2166	.611
			10.3	534	1941	2120	.936
			14.5	528	1875	2070	1.082
	385		1.3	540	1924	2076	.562
			5.9	541	1929	2080	.799
			10.3	534	1841	2010	1.093
			14.5	525	1745	1937	1.250
	488		1.3	539	1855	2009	.610
			5.9	536	1818	1979	.910
			10.3	531	1761	1934	1.173
			14.5	521	1641	1834	1.306
	127	3.1	1.3	536	2069	2250	.299
			5.9	536	2067	2250	.470
			10.3	534	2033	2220	.671
			14.5	531	2003	2200	.788
	254		1.3	540	2012	2172	.391
			5.9	540	2010	2170	.632
			10.3	534	1941	2119	.922
			14.5	528	1874	2068	1.082
	385		1.3	532	1941	2127	.515
			5.9	541	1933	2080	.778
			10.3	534	1844	2010	1.074
			14.5	525	1748	1940	1.241
	488		1.3	538	1842	1997	.593
			5.9	537	1828	1986	.907
			10.3	531	1760	1932	1.146
			14.5	521	1658	1854	1.323
	127	0.6	1.3	536	2074	2254	.304
			5.9	536	2070	2250	.467
			10.3	533	2033	2223	.675
			14.5	531	2001	2197	.703
	254		1.3	541	2027	2184	.407
			5.9	540	2015	2175	.648
			10.3	534	1938	2114	.940
			14.5	528	1868	2063	1.089
	385		1.3	542	1942	2089	.520
			5.9	542	1931	2077	.754
			10.3	533	1830	2002	1.114
			14.5	524	1726	1920	1.267

α (°)	q (lbs/ft.²)	Flap Opening (inches) Oil	Flap Opening (inches) Coolant	T (°abs.)	P_{static} (lbs/ft.²)	ρ (slugs/ft.³ ×10⁻⁶)	m (slugs/sec.)
-2	488	0.6	1.3	539	1865	2017	.584
			5.9	538	1842	1495	.894
			10.3	531	1766	1940	1.158
			14.5	519	1629	1831	1.334
+.56	127		1.3	536	2074	2255	.317
			5.9	533	2030	2220	.476
			10.3	533	2032	2223	.679
			14.5	531	1998	2193	.809
	254		1.3	540	2016	2176	.469
			5.9	540	2018	2178	.678
			10.3	534	1938	2117	.959
			14.5	527	1863	2060	1.106
	385		1.3	542	1966	2116	.602
			5.9	542	1938	2087	.827
			10.3	532	1821	1994	1.173
			14.5	520	1685	1889	1.322
	127	3.1	1.3	536	2066	2247	.332
			5.9	536	2068	2249	.479
			10.3	534	2034	2220	.653
			14.5	531	2003	2199	.796
	254		1.3	539	2012	2175	.464
			5.9	539	2005	2168	.687
			10.3	534	1936	2114	.961
			14.5	528	1868	2063	1.090
	385		1.3	542	1950	2098	.584
			5.9	542	1936	2083	.818
			10.3	533	1831	2002	1.141
			14.5	523	1710	1906	1.330
	127	8.0	1.3	536	2066	2248	.341
			5.9	536	2067	2249	.489
			10.3	533	2030	2221	.698
			14.5	531	1998	2193	.815
	254		1.3	539	2002	2165	.488
			5.9	538	1997	2163	.681
			10.3	534	1934	2112	.950
			14.5	528	1868	2063	1.106
	385		1.3	542	1943	2090	.580
			5.9	542	1939	2089	.814
			10.3	533	1835	2006	1.134
			14.5	523	1715	1913	1.322

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TABLE II

DIVIDED DUCT WITH LIP EXTENSION - OIL
RADIATOR DUCT ENTRANCE CONDITIONS
AREA = 38.6 SQ. IN.

α °	q LBS/FT.^{2}	FLAP OPENING INCHES OIL	FLAP OPENING INCHES COOLANT	T °ABS.	P_{STATIC} LBS./FT.^{2}	ρ SLUGS/FT.^{3} $\times 10^{-6}$	m SLUGS/SEC.
-2	127	8.0	1.3	528	1964	2169	.197
			5.9	528	1966	2169	.214
			10.3	529	1969	2169	.213
			14.5	529	1972	2175	.203
	254		1.3	521	1785	1998	.280
			5.9	522	1790	2000	.290
			10.3	522	1794	2003	.281
			14.5	523	1806	2013	.269
	385		1.3	513	1591	1807	.301
			5.9	513	1600	1819	.320
			10.3	513	1601	1819	.311
			14.5	515	1622	1836	.306
	488		1.3	502	1449	1685	.318
			5.9	501	1431	1667	.330
			10.3	502	1443	1679	.333
			14.5	501	1433	1667	.323
	127	3.1	1.3	534	2046	2233	.136
			5.9	535	2055	2239	.146
			10.3	535	2055	2239	.144
			14.5	535	2055	2239	.140
	254		1.3	536	1972	2145	.192
			5.9	538	1988	2151	.201
			10.3	538	1988	2151	.198
			14.5	537	1977	2146	.190
	385		1.3	538	1892	2046	.220
			5.9	540	1924	2077	.237
			10.3	540	1915	2068	.237
			14.5	539	1900	2058	.227
	488		1.3	534	1801	1965	.233
			5.9	539	1866	2017	.265
			10.3	539	1857	2006	.266
			14.5	538	1842	1994	.249
	127	0.6	1.3	538	2104	2280	.052
			5.9	539	2115	2289	.044
			10.3	539	2113	2287	.050
			14.5	539	2109	2281	.053
	254		1.3	545	2085	2233	.081
			5.9	547	2108	2245	.073
			10.3	546	2105	2250	.073
			14.5	546	2096	2239	.071
	385		1.3	549	2029	2155	.103
			5.9	553	2091	2204	.091
			10.3	554	2095	2205	.092
			14.5	553	2078	2190	.088

α °	q LBS/FT.^{2}	FLAP OPENING INCHES OIL	FLAP OPENING INCHES COOLANT	T °ABS.	P_{STATIC} LBS/FT.^{3}	ρ SLUGS/FT.^{3} $\times 10^{-6}$	m SLUGS/SEC.
-2	488	0.6	1.3	548	1965	2091	.119
			5.9	557	2086	2183	.103
			10.3	557	2087	2184	.104
			14.5	557	2081	2179	.102
+.56	127		1.3	538	2098	2273	.049
			5.9	536	2074	2256	.050
			10.3	544	2113	2264	.047
			14.5	538	2106	2282	.053
	254		1.3	543	2063	2214	.087
			5.9	547	2108	2247	.064
			10.3	546	2101	2243	.070
			14.5	545	2088	2234	.073
	385		1.3	550	2046	2169	.111
			5.9	553	2087	2200	.089
			10.3	553	2086	2199	.094
			14.5	552	2075	2192	.102
	127	3.1	1.3	534	2043	2230	.126
			5.9	535	2057	2242	.143
			10.3	535	2058	2243	.141
			14.5	535	2051	2235	.128
	254		1.3	535	1961	2137	.182
			5.9	537	1981	2151	.192
			10.3	537	1984	2154	.194
			14.5	536	1973	2146	.184
	385		1.3	535	1861	2029	.215
			5.9	539	1910	2066	.245
			10.3	539	1903	2058	.236
			14.5	538	1885	2042	.228
	127	8.0	1.3	529	1971	2172	.191
			5.9	529	1975	2177	.212
			10.3	528	1967	2172	.212
			14.5	529	1975	2177	.193
	254		1.3	522	1791	2000	.265
			5.9	521	1784	1996	.289
			10.3	522	1795	2005	.277
			14.5	523	1809	2017	.258
	385		1.3	512	1594	1815	.302
			5.9	513	1609	1829	.297
			10.3	513	1604	1823	.301
			14.5	515	1626	1841	.296

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TABLE III

MODIFIED DIVIDED DUCT - COOLANT

RADIATOR DUCT ENTRANCE CONDITIONS

AREA = 138.7 SQ.IN.

α °	q LBS./FT.²	Flap Opening Inches: Oil	Flap Opening Inches: Coolant	T °ABS.	P_{static} LBS/FT.²	ρ SLUGS/FT.³ ×10⁻⁶	m SLUGS/SEC.
-2	127	8.0	1.3	539	2109	2280	,242
			5.9	529	2064	2274	.496
			10.3	518	2008	2260	,686
			14.5	519	1979	2222	.758
	254		1.3	545	2092	2238	.343
			5.9	539	2003	2166	.688
			10.3	529	1879	2070	.928
			14.5	525	1826	2028	1.024
	385		1.3	552	2066	2182	.446
			5.9	518	1940	2183	.838
			10.3	528	1774	1959	1.078
			14.5	520	1682	1886	1.220
	488		1.3	553	2034	2144	.499
			5.9	543	1895	2034	.887
			10.3	521	1647	1843	1.203
			14.5	512	1552	1766	1.267
	127	3.1	1.3	539	2110	2282	.227
			5.9	536	2068	2247	.470
			10.3	536	2069	2250	.467
			14.5	529	1977	2180	.758
	254		1.3	545	2090	2237	.350
			5.9	540	2015	2176	.652
			10.3	525	1898	2108	.919
			14.5	524	1826	2032	1.028
	385		1.3	551	2058	2178	.455
			5.9	524	1955	2175	.796
			10.3	529	1783	1965	1.074
			14.5	520	1682	1886	1.192
	488		1.3	550	1999	2119	.568
			5.9	—	—	—	—
			10.3	525	1695	1882	1.167
			14.5	—	—	—	—
	127	0.6	1.3	539	2110	2283	.228
			5.9	536	2069	2250	.470
			10.3	532	2013	2206	.667
			14.5	514	1979	2244	.765
	254		1.3	546	2097	2240	.316
			5.9	539	2005	2169	.683
			10.3	530	1894	2083	.920
			14.5	525	1826	2028	1.026
	385		1.3	552	2072	2189	.412
			5.9	542	1944	2093	.804
			10.3	528	1768	1951	1.090
			14.5	519	1666	1871	1.190
-2	488	0.6	1.3	552	2024	2139	.501
			5.9	539	1860	2012	.933
			10.3	524	1687	1877	1.172
			14.5	512	1551	1766	1.264
+.56	127		1.3	539	2111	2283	.210
			5.9	536	2069	2250	.458
			10.3	531	2006	2203	.679
			14.5	528	1966	2170	.779
	254		1.3	546	2099	2240	.301
			5.9	540	2014	2173	.653
			10.3	529	1881	2074	.941
			14.5	523	1800	2008	1.057
	385		1.3	553	2089	2200	.359
			5.9	543	1957	2103	.791
			10.3	525	1742	1934	1.123
			14.5	514	1616	1834	1.224
	127	3.1	1.3	539	2109	2280	.214
			5.9	522	2067	2310	.481
			10.3	531	2004	2200	.684
			14.5	529	1969	2170	.775
	254		1.3	546	2099	2240	.307
			5.9	539	2010	2173	.665
			10.3	529	1880	2071	.943
			14.5	523	1803	2009	1.053
	385		1.3	553	2089	2203	.357
			5.9	542	1944	2090	.815
			10.3	524	1730	1924	1.135
			14.5	517	1647	1857	1.201
	127	8.0	1.3	539	2110	2283	.228
			5.9	536	2068	2248	.477
			10.3	531	2007	2203	.679
			14.5	529	1969	2170	.774
	254		1.3	546	2099	2240	.314
			5.9	539	2011	2176	.664
			10.3	529	1881	2073	.949
			14.5	523	1804	2011	1.051
	385		1.3	553	2089	2202	.366
			5.9	543	1953	2096	.798
			10.3	526	1743	1933	1.121
			14.5	515	1620	1837	1.214

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TABLE IV

MODIFIED DIVIDED DUCT - OIL

RADIATOR DUCT ENTRANCE CONDITIONS

AREA = 38.6 SQ.IN.

α °	q LBS./FT.²	Flap Opening Inches Oil	Flap Opening Inches Coolant	T °ABS.	P_{STATIC} LBS./FT.²	ρ SLUGS/FT.³ ×10⁻⁶	m SLUGS/SEC.
-2	127	8.0	1.3	528	1964	2169	.214
			5.9	528	1959	2162	.218
			10.3	528	1962	2168	.217
			14.5	529	1968	2170	.214
	254		1.3	521	1780	1992	.282
			5.9	519	1757	1975	.290
			10.3	520	1770	1985	.288
			14.5	521	1784	1996	.273
	385		1.3	511	1581	1805	.307
			5.9	511	1581	1805	.311
			10.3	512	1588	1810	.304
			14.5	512	1598	1821	.299
	488		1.3	499	1417	1656	.331
			5.9	499	1414	1652	.332
			10.3	497	1397	1640	.322
			14.5	497	1397	1640	.325
	127	3.1	1.3	—	—	—	—
			5.9	534	2052	2240	.147
			10.3	535	2056	2246	.146
			14.5	534	2049	2234	.146
	254		1.3	538	1987	2154	.200
			5.9	538	1983	2150	.203
			10.3	537	1981	2151	.203
			14.5	537	1983	2153	.201
	385		1.3	540	1916	2070	.242
			5.9	540	1914	2067	.244
			10.3	540	1920	2072	.244
			14.5	539	1905	2060	.239
	488		1.3	538	1849	2004	.264
			5.9	539	1857	2010	.268
			10.3	538	1839	1993	.269
			14.5	537	1833	1990	.269
	127	0.6	1.3	539	2112	2284	.047
			5.9	539	2111	2283	.050
			10.3	539	2112	2284	.050
			14.5	539	2111	2283	.050
	254		1.3	546	2105	2250	.074
			5.9	546	2102	2248	.078
			10.3	546	2102	2248	.079
			14.5	546	2102	2248	.071
	385		1.3	553	2094	2209	.093
			5.9	553	2091	2204	.093
			10.3	553	2091	2204	.098
			14.5	553	2087	2202	.099

α °	q LBS./FT.²	Flap Opening Inches Oil	Flap Opening Inches Coolant	T °ABS.	P_{STATIC} LBS./FT.²	ρ SLUGS/FT.³ ×10⁻⁶	m SLUGS/SEC.
-2	488		1.3	557	2077	2174	.108
			5.9	556	2073	2174	.112
			10.3	557	2082	2180	.113
			14.5	557	2077	2174	.106
+.56	127		1.3	539	2108	2280	.044
			5.9	539	2113	2285	.051
			10.3	539	2112	2285	.052
			14.5	539	2108	2280	.053
	254		1.3	546	2098	2240	.075
			5.9	546	2104	2247	.073
			10.3	546	2103	2247	.079
			14.5	546	2097	2240	.073
	385		1.3	553	2088	2201	.093
			5.9	554	2095	2204	.093
			10.3	553	2088	2201	.097
			14.5	553	2085	2199	.088
	127		1.3	535	2055	2240	.140
			5.9	535	2056	2241	.146
			10.3	535	2055	2240	.145
			14.5	535	2054	2239	.131
	254		1.3	538	1985	2152	.203
			5.9	538	1985	2152	.203
			10.3	538	1985	2152	.203
			14.5	537	1982	2153	.194
	385		1.3	541	1926	2077	.232
			5.9	539	1905	2061	.247
			10.3	539	1903	2059	.245
			14.5	540	1917	2070	.225
	127		1.3	528	1962	2167	.211
			5.9	528	1962	2167	.214
			10.3	529	1972	2174	.215
			14.5	529	1970	2172	.211
	254		1.3	521	1777	1986	.282
			5.9	521	1772	1983	.288
			10.3	521	1781	1993	.277
			14.5	521	1795	2007	.278
	385		1.3	512	1596	1819	.305
			5.9	512	1594	1815	.311
			10.3	512	1596	1819	.334
			14.5	512	1592	1814	.309

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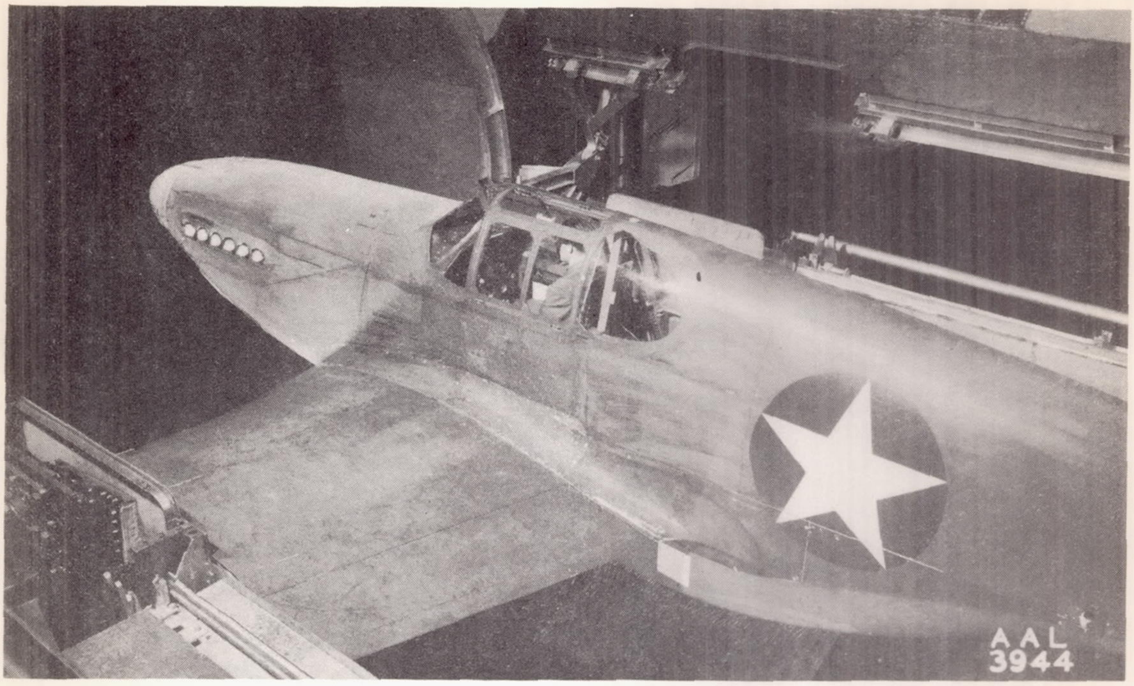


Figure 1.- Three-quarter rear view of the airplane mounted in the 16-foot wind tunnel.

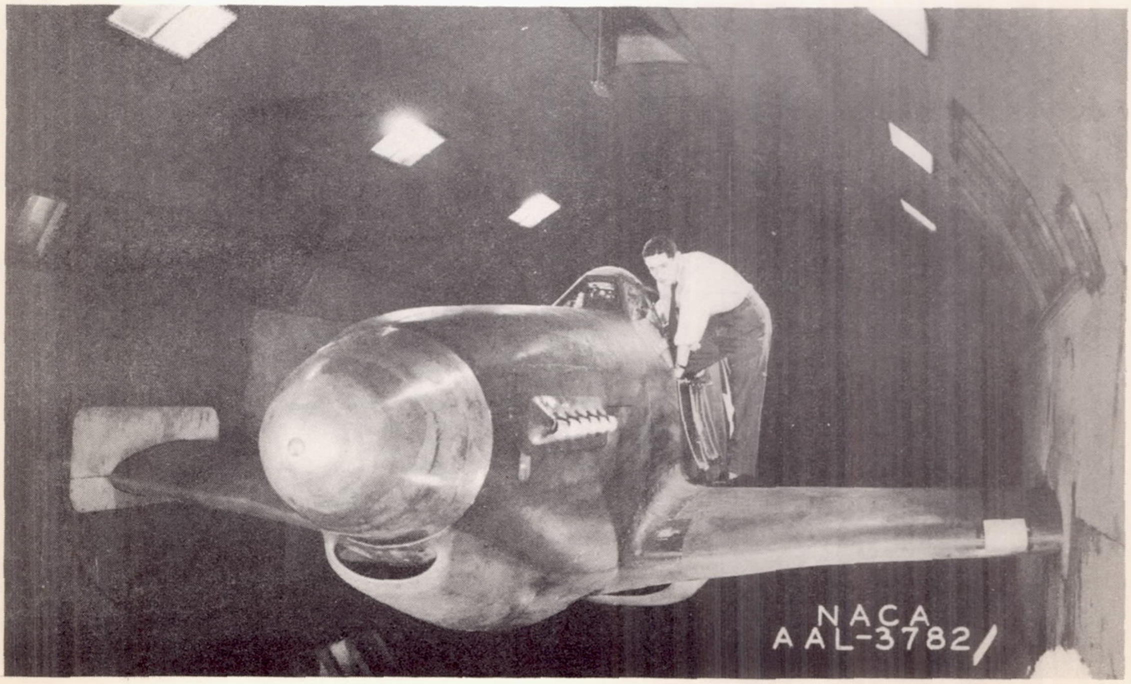
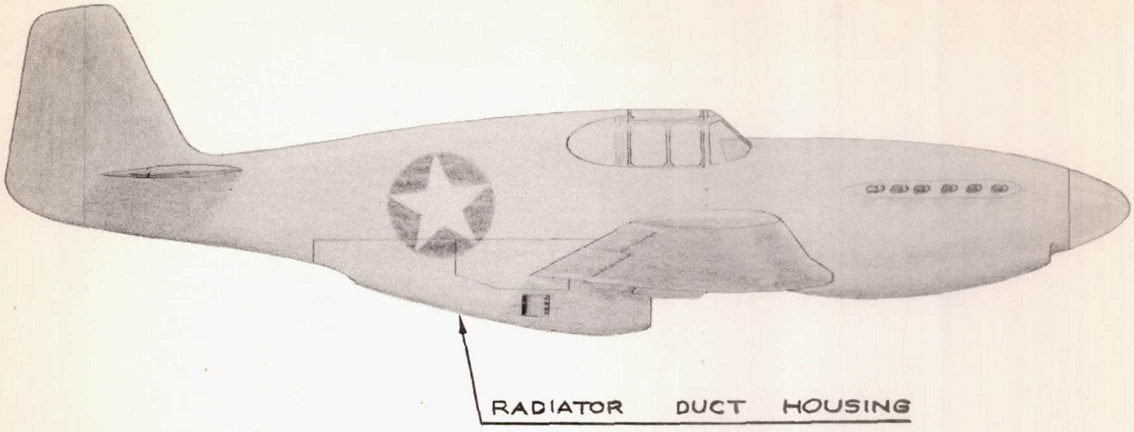
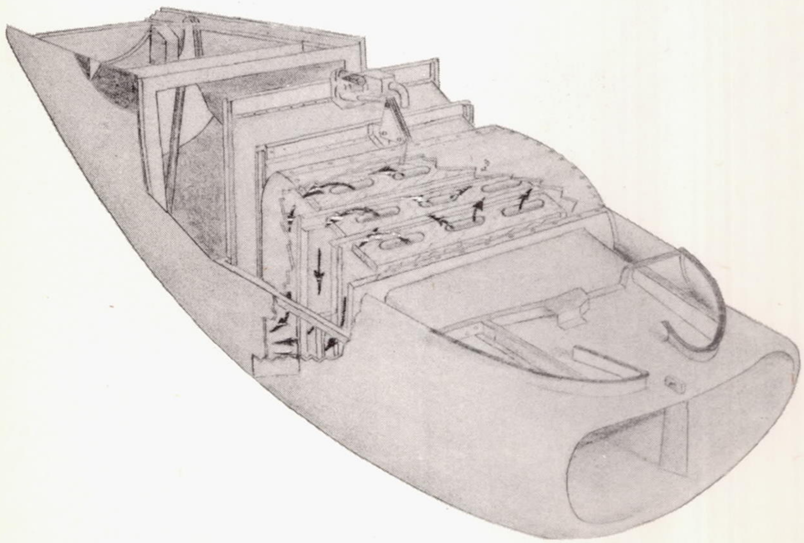


Figure 2.- Three-quarter front view of the airplane mounted in the 16-foot wind tunnel.





RADIATOR DUCT HOUSING REMOVED; SHOWING LOCATION OF LOUVERS; SHIELD OVER LOUVERS; AND FLOW OF AIR FROM LOUVERS, DOWN THE SIDE AND OUT THE SIDE EXIT.

FIGURE 3.- BY-PASS ARRANGEMENT ON ORIGINAL DUCT

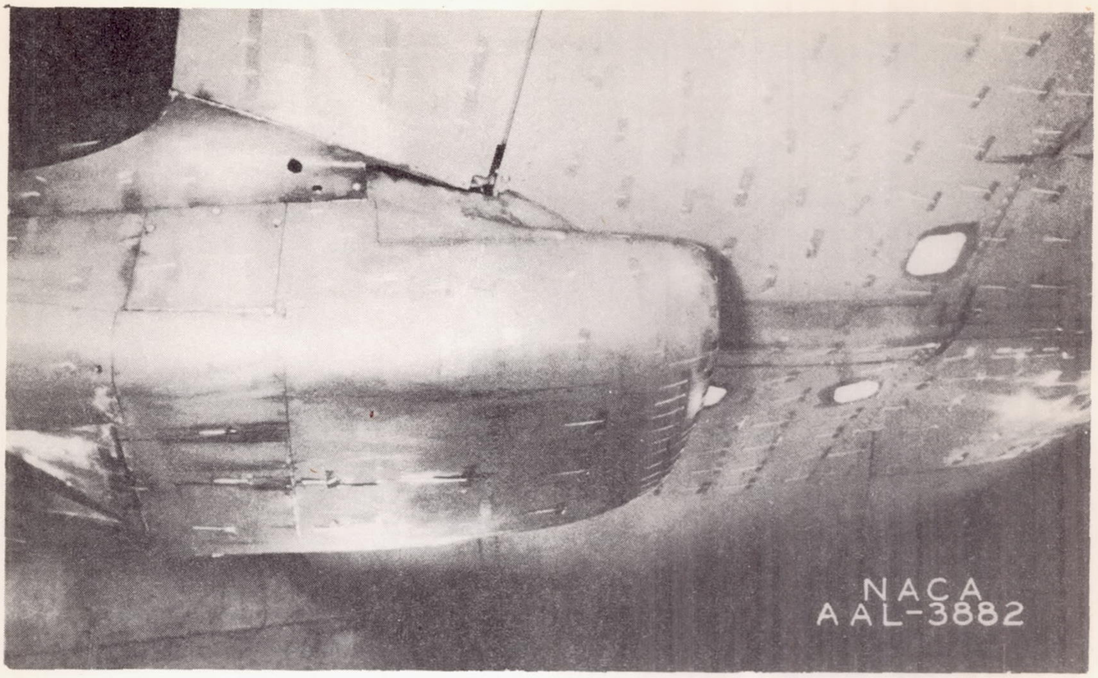


Figure 4.- Side view of original duct. $\alpha = -2^\circ$, flaps closed.

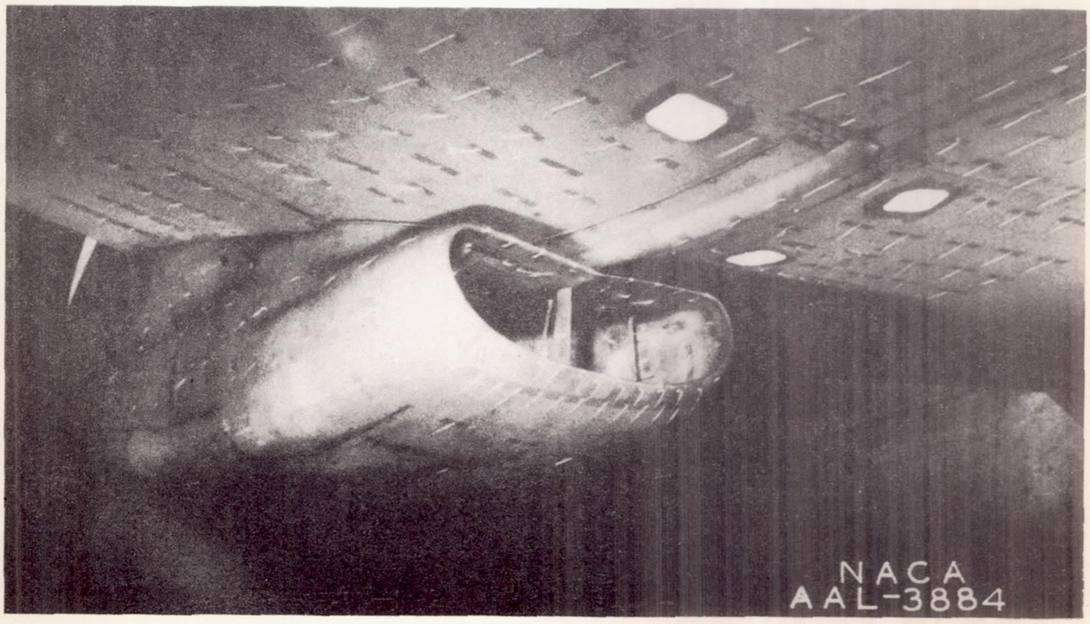


Figure 5.- Three-quarter front view of original **duct** entrance. $\alpha = -2^\circ$, flaps closed.

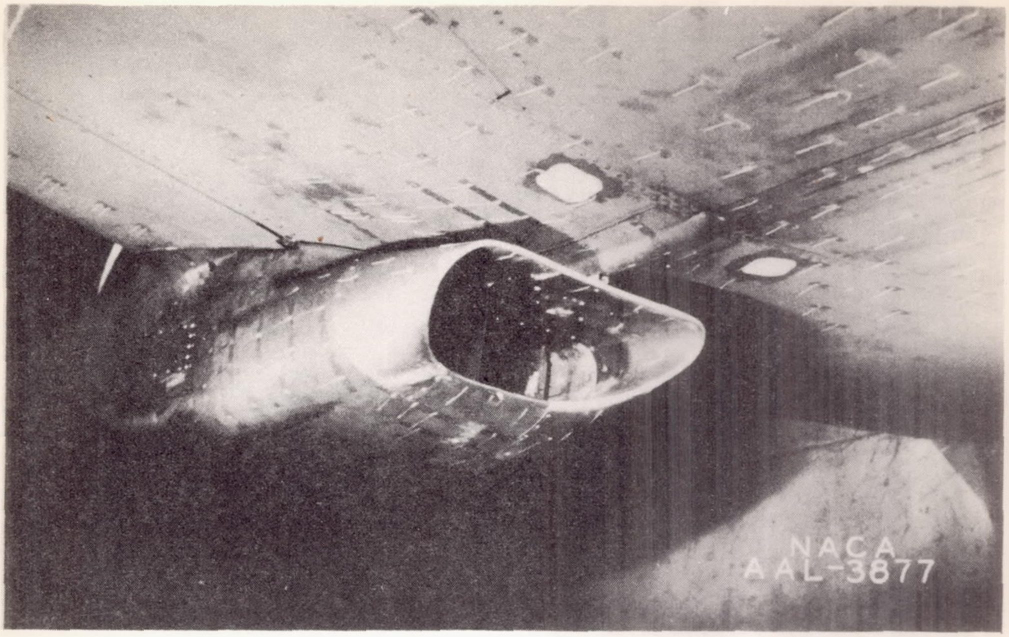


Figure 6.- Three-quarter front view of original duct with lip extension. $\alpha = -2^{\circ}$, flaps closed, bypass half open

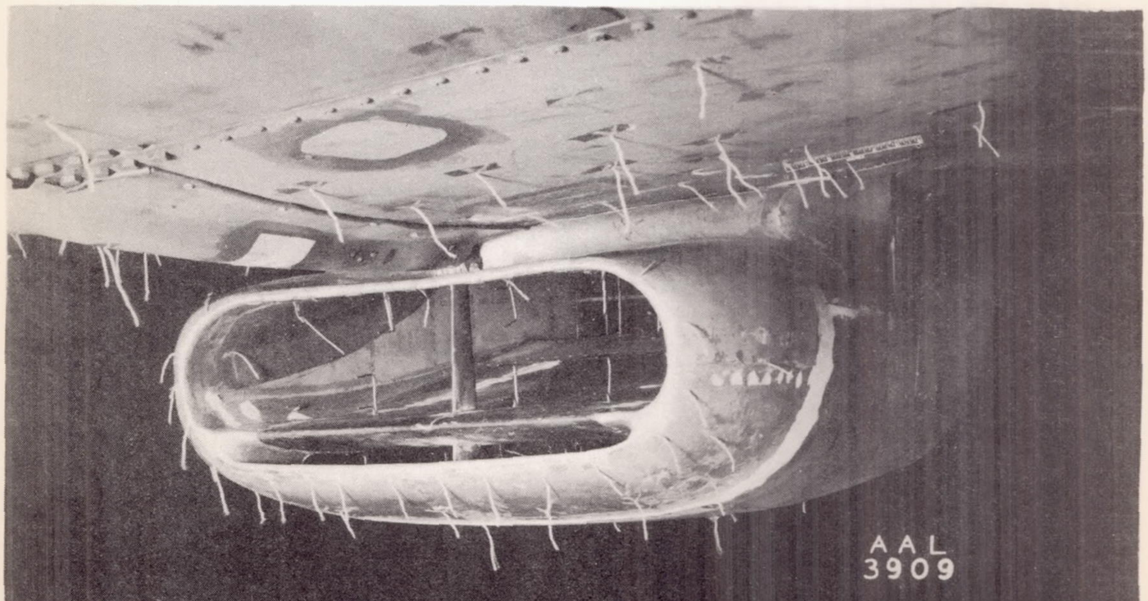


Figure 7.- Three-quarter front view of the divided duct.

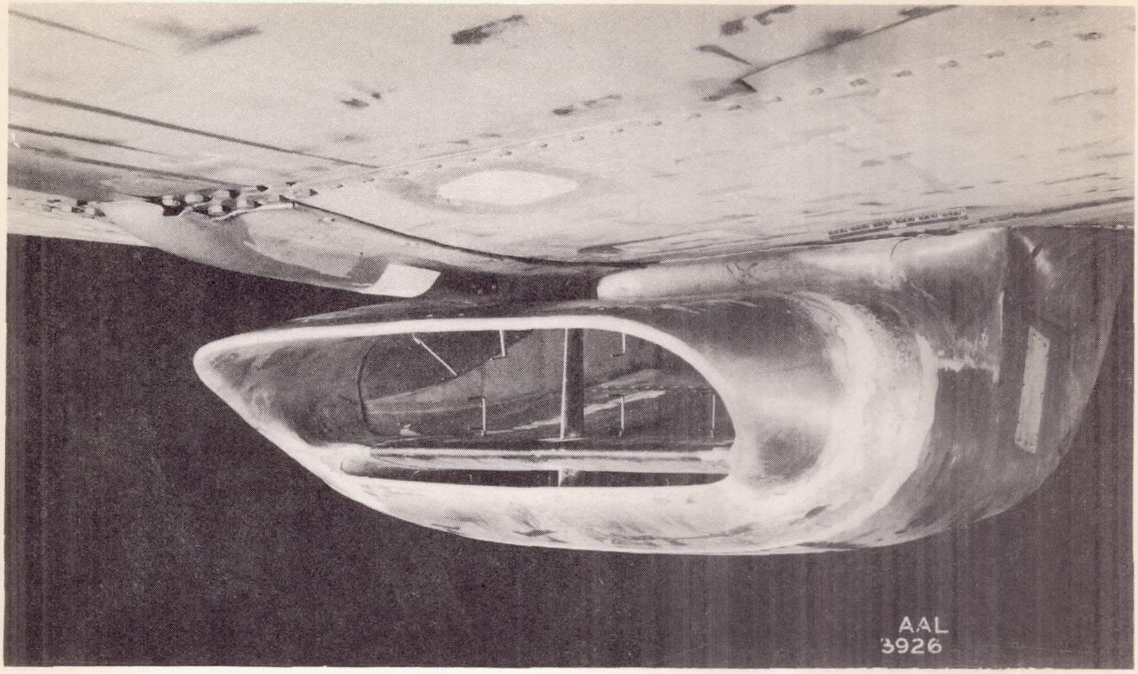


Figure 8.- Three-quarter front view of the divided duct with lip extension.

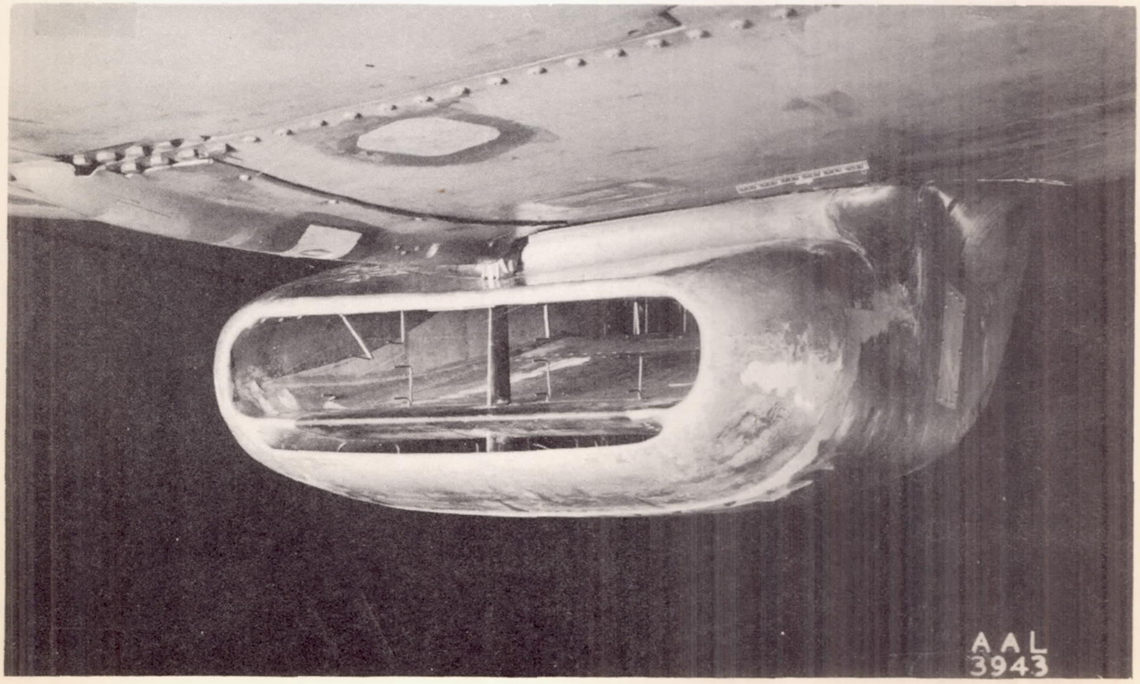


Figure 9.- Three-quarter front view of the modified divided duct.

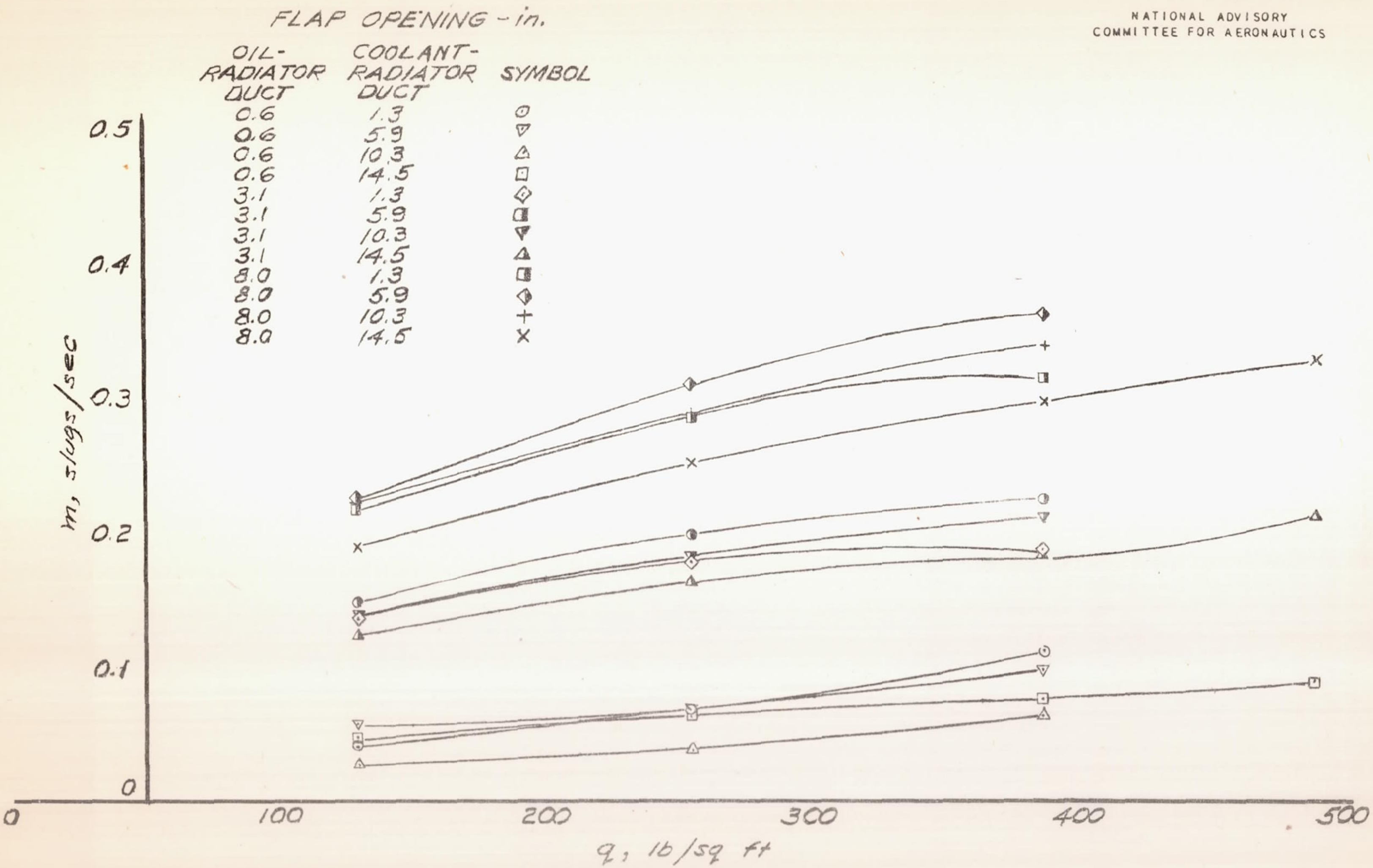


FIGURE 10.- MASS FLOW THROUGH OIL-RADIATOR DUCT FOR ORIGINAL DESIGN. $\alpha = -2°$

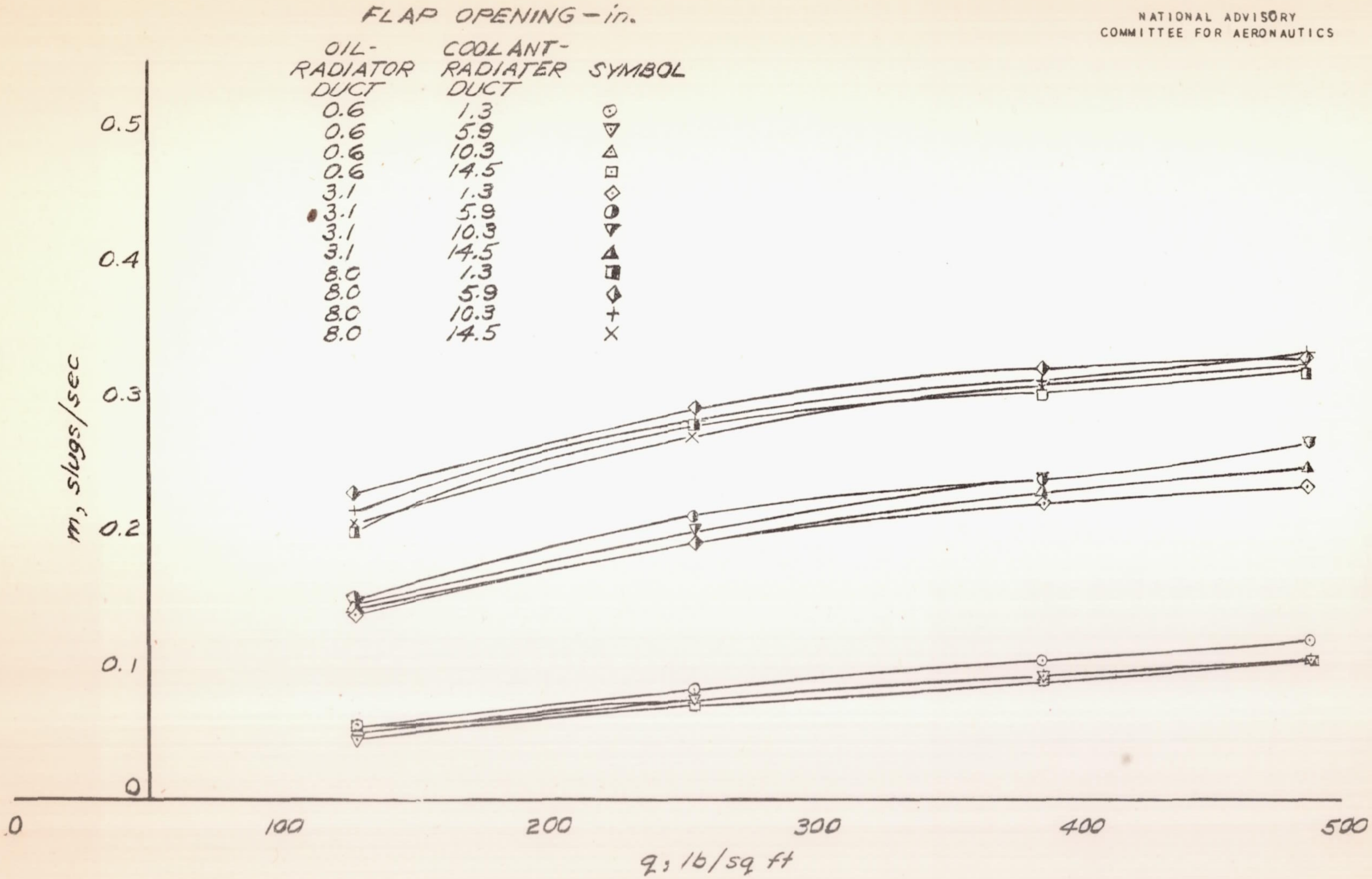


FIGURE 11.- MASS FLOW THROUGH OIL-RADIATOR DUCT FOR DIVIDED DUCT WITH LIP EXTENSION. $\alpha = -2°$

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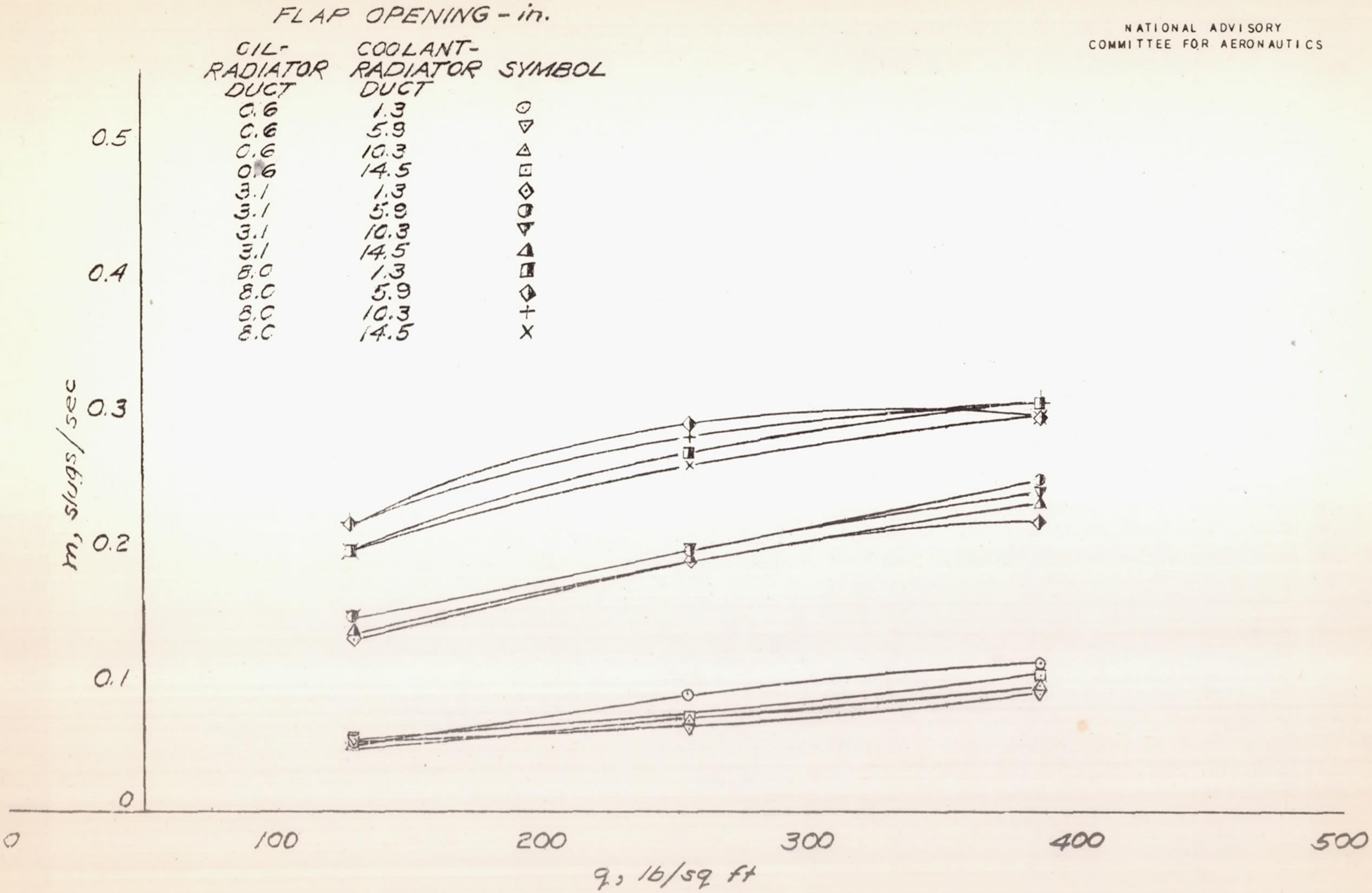

FIGURE 12.- MASS FLOW THROUGH OIL-RADIATOR DUCT FOR DIVIDED DUCT WITH LIP EXTENSION. $\alpha = 0.56°$

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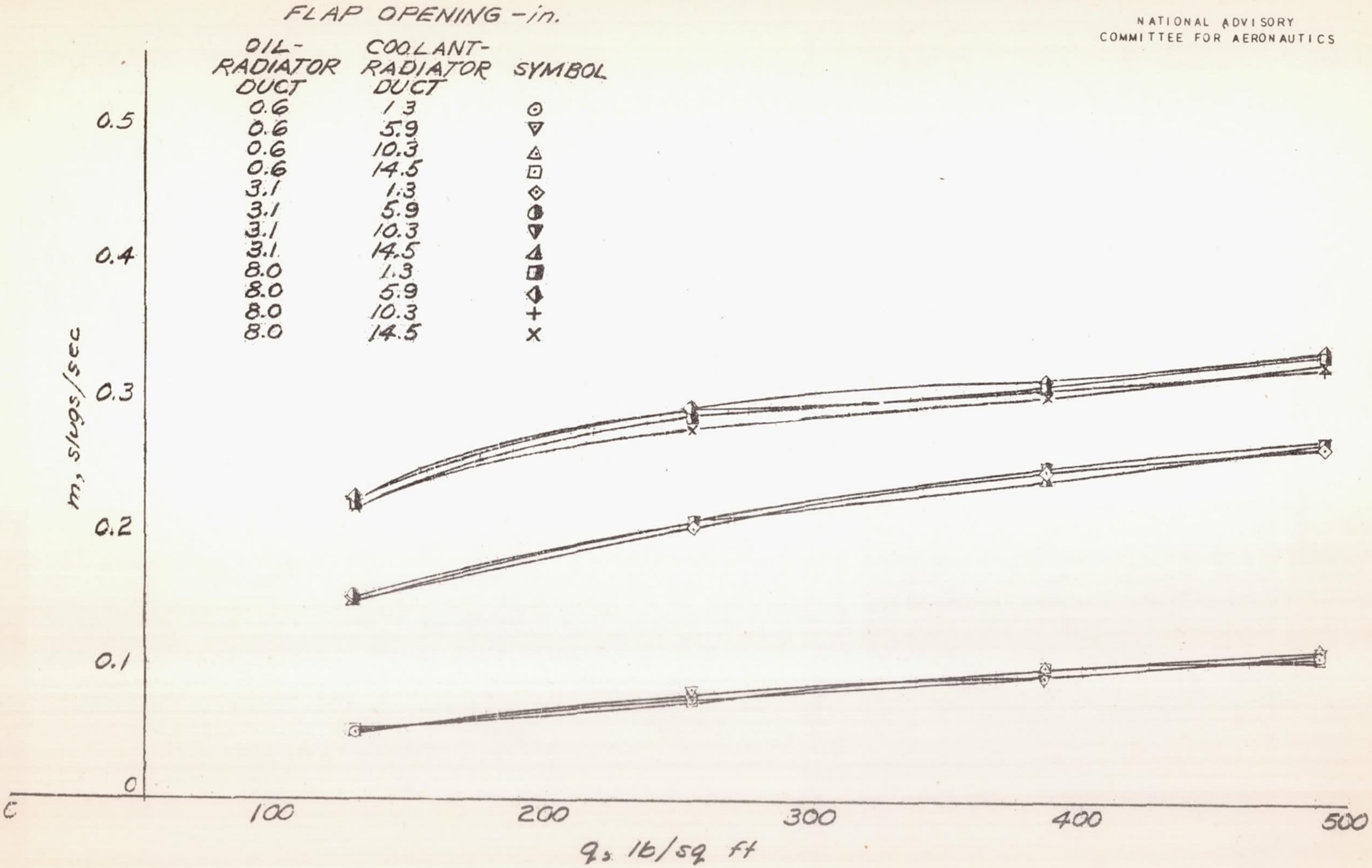

FIGURE 13.- MASS FLOW THROUGH OIL-RADIATOR DUCT FOR DIVIDED DUCT $\alpha = -2°$

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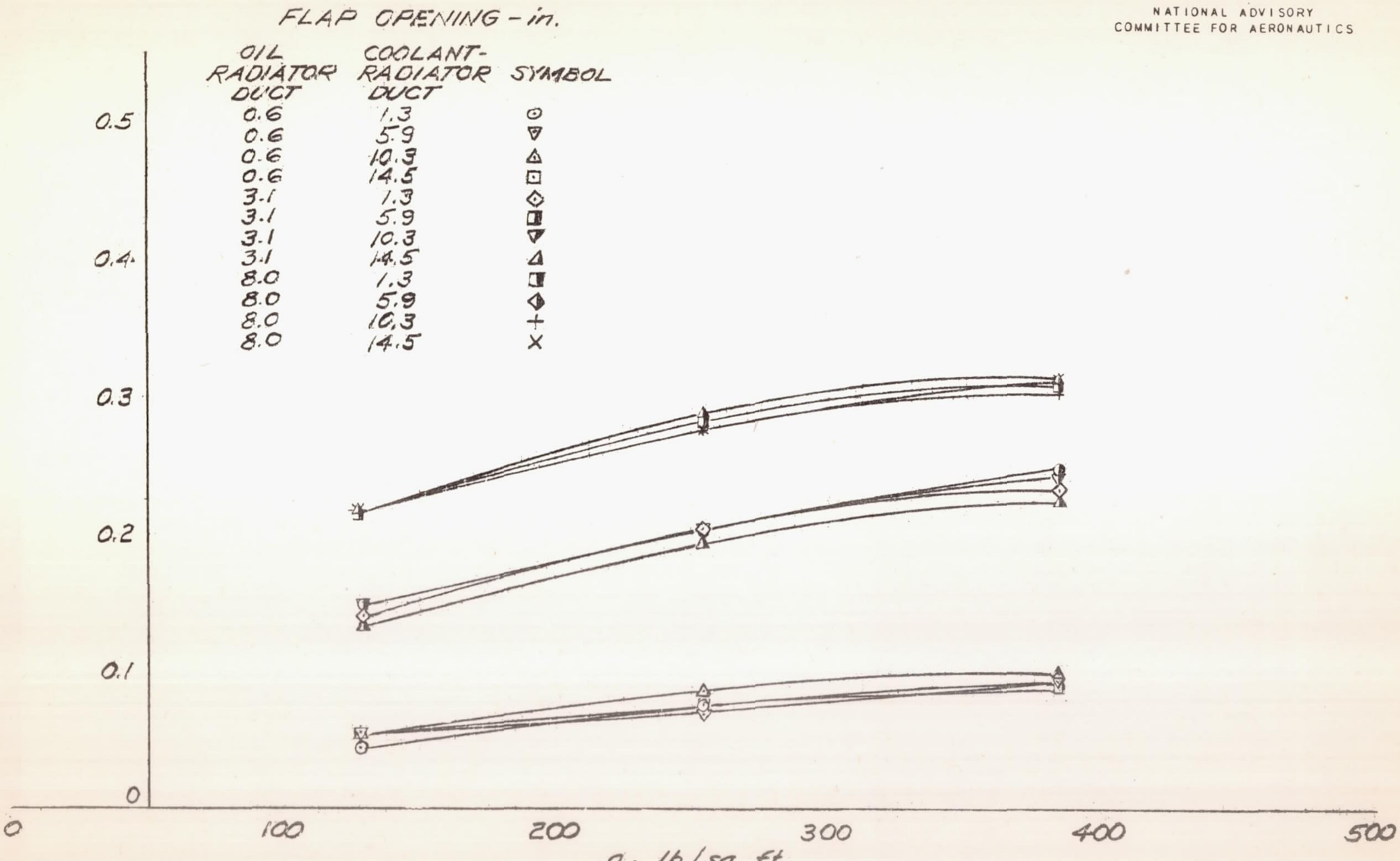

FIGURE 14.- MASS FLOW THROUGH OIL-RADIATOR DUCT FOR MODIFIED DIVIDED DUCT. $\alpha = 0.56°$

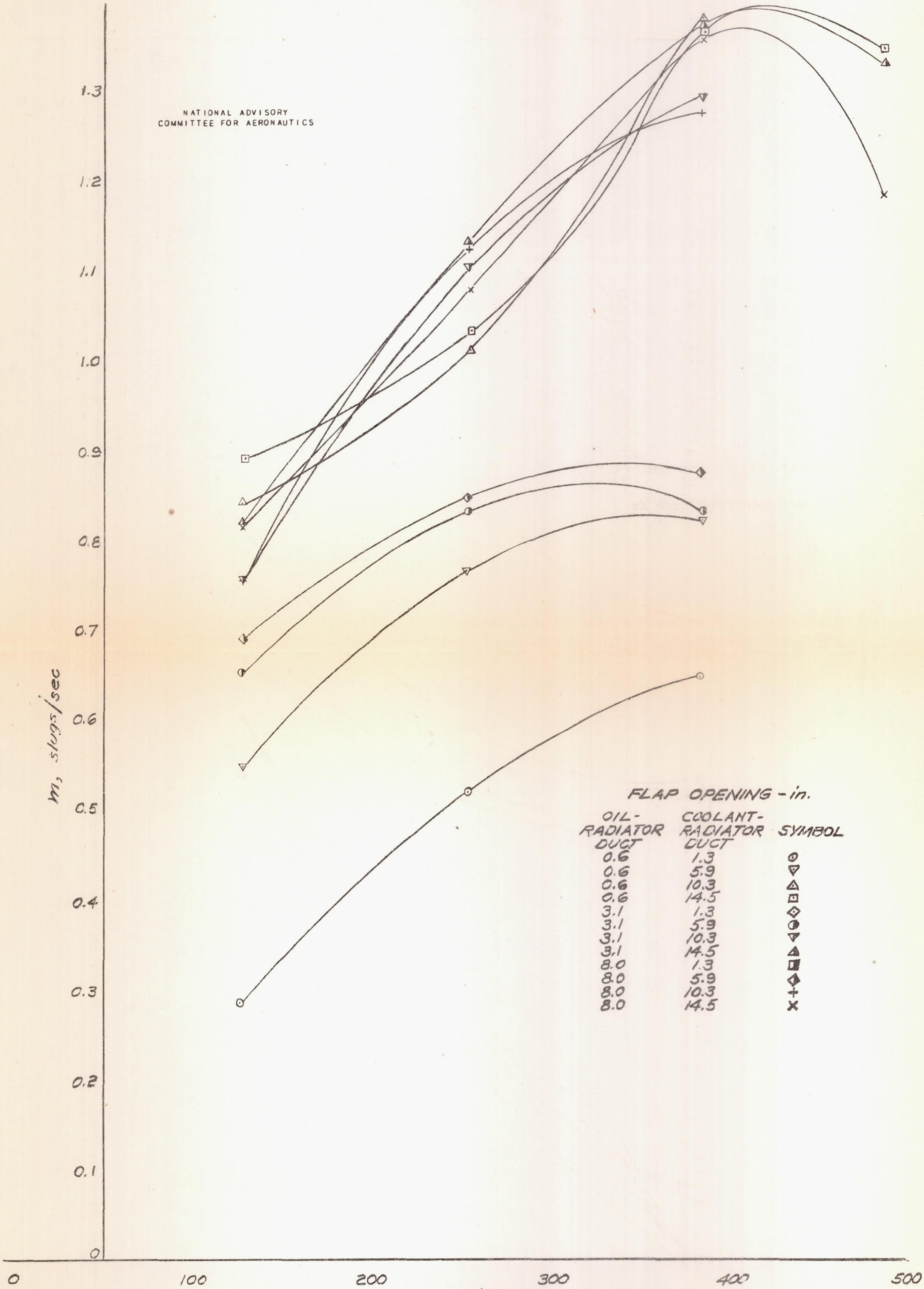

FIGURE 15.- MASS FLOW THROUGH COOLANT-RADIATOR DUCT FOR ORIGINAL DESIGN. $\alpha = -2°$

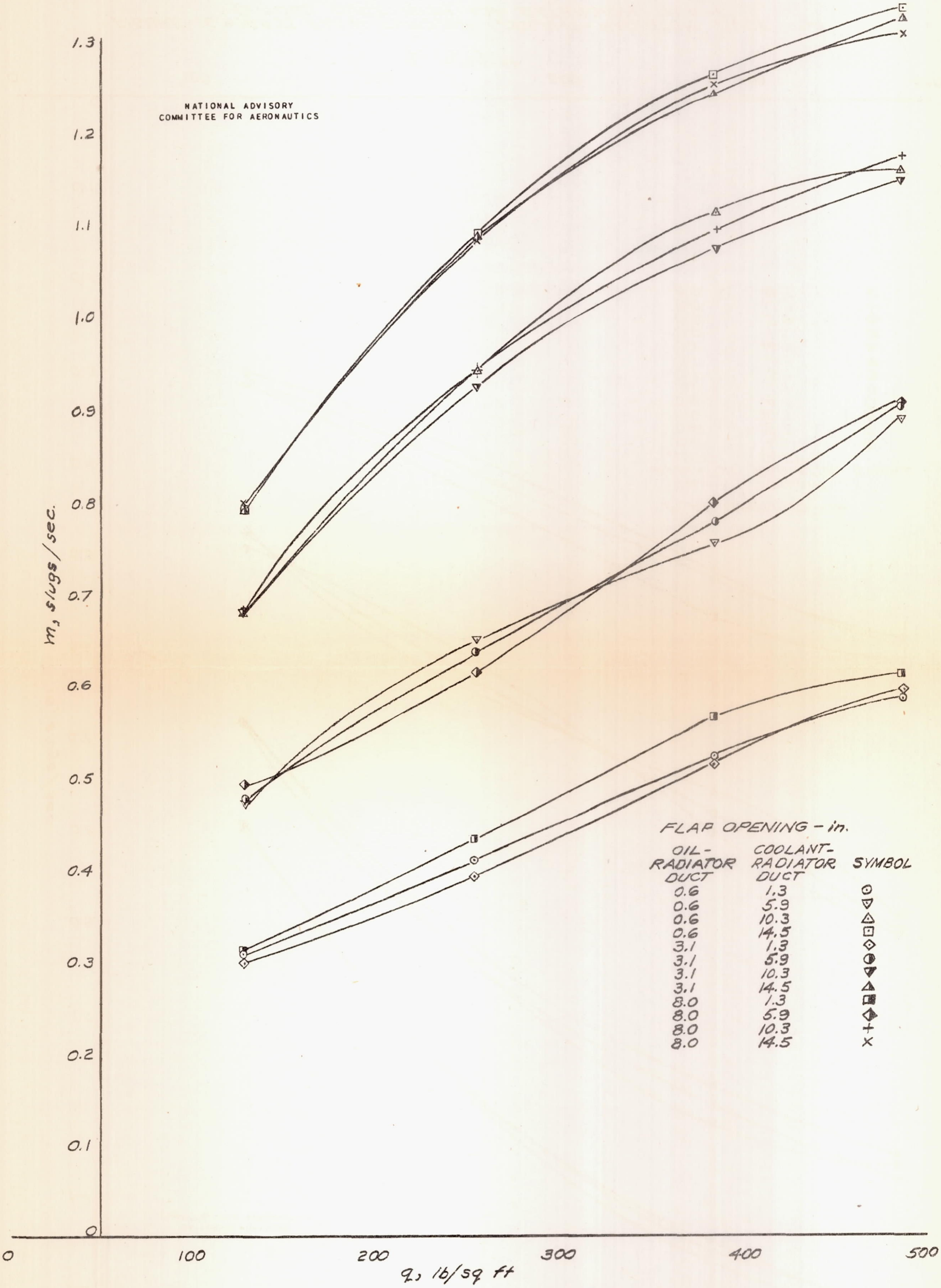

FIGURE 16.- MASS FLOW THROUGH COOLANT-RADIATOR DUCT FOR DIVIDED DUCT WITH LIP EXTENSION. $\alpha = -2°$

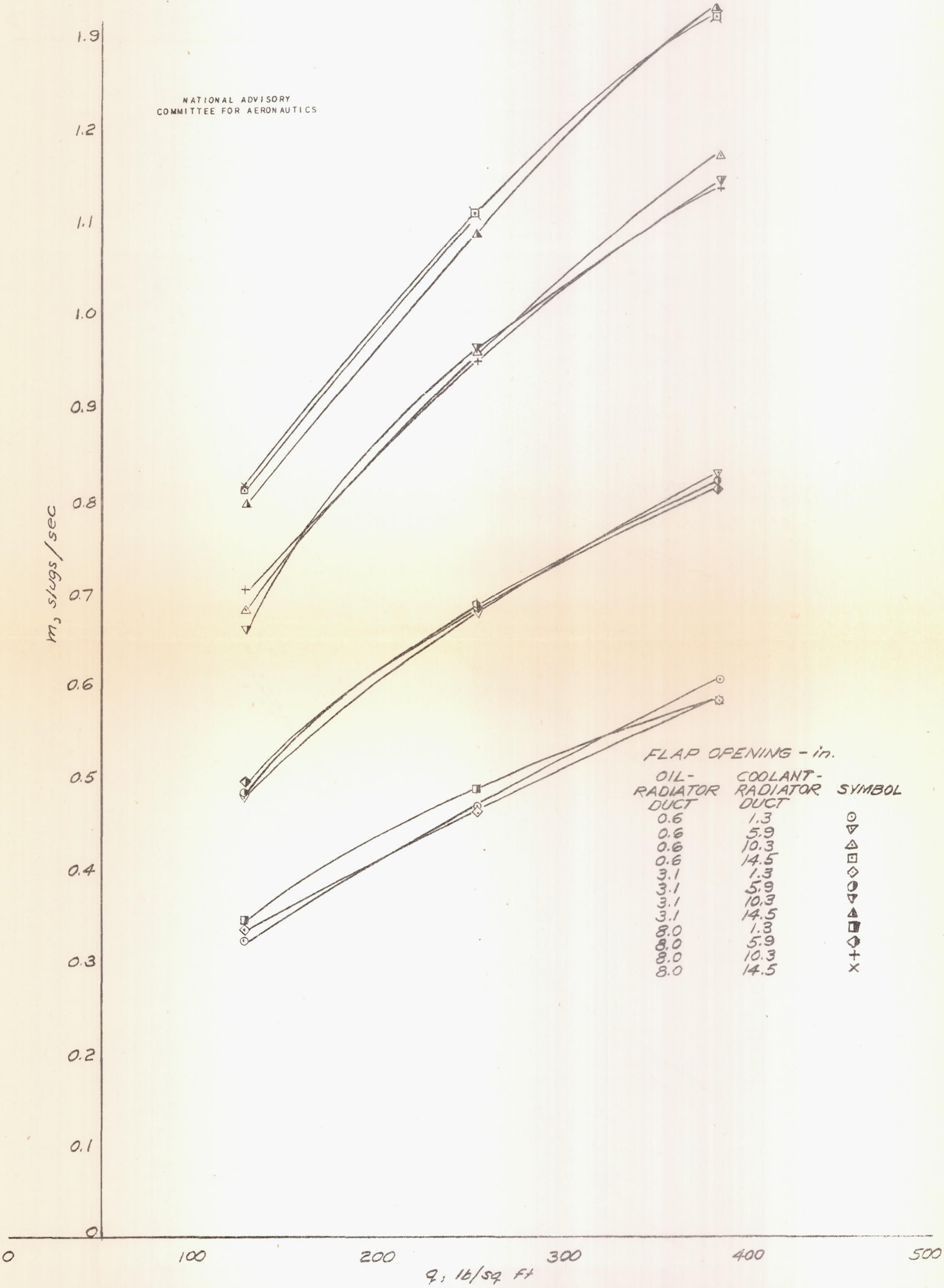

FIGURE 17.- MASS FLOW THROUGH COOLANT-RADIATOR DUCT FOR DIVIDED DUCT WITH LIP EXTENSION. $\alpha = 0.56°$

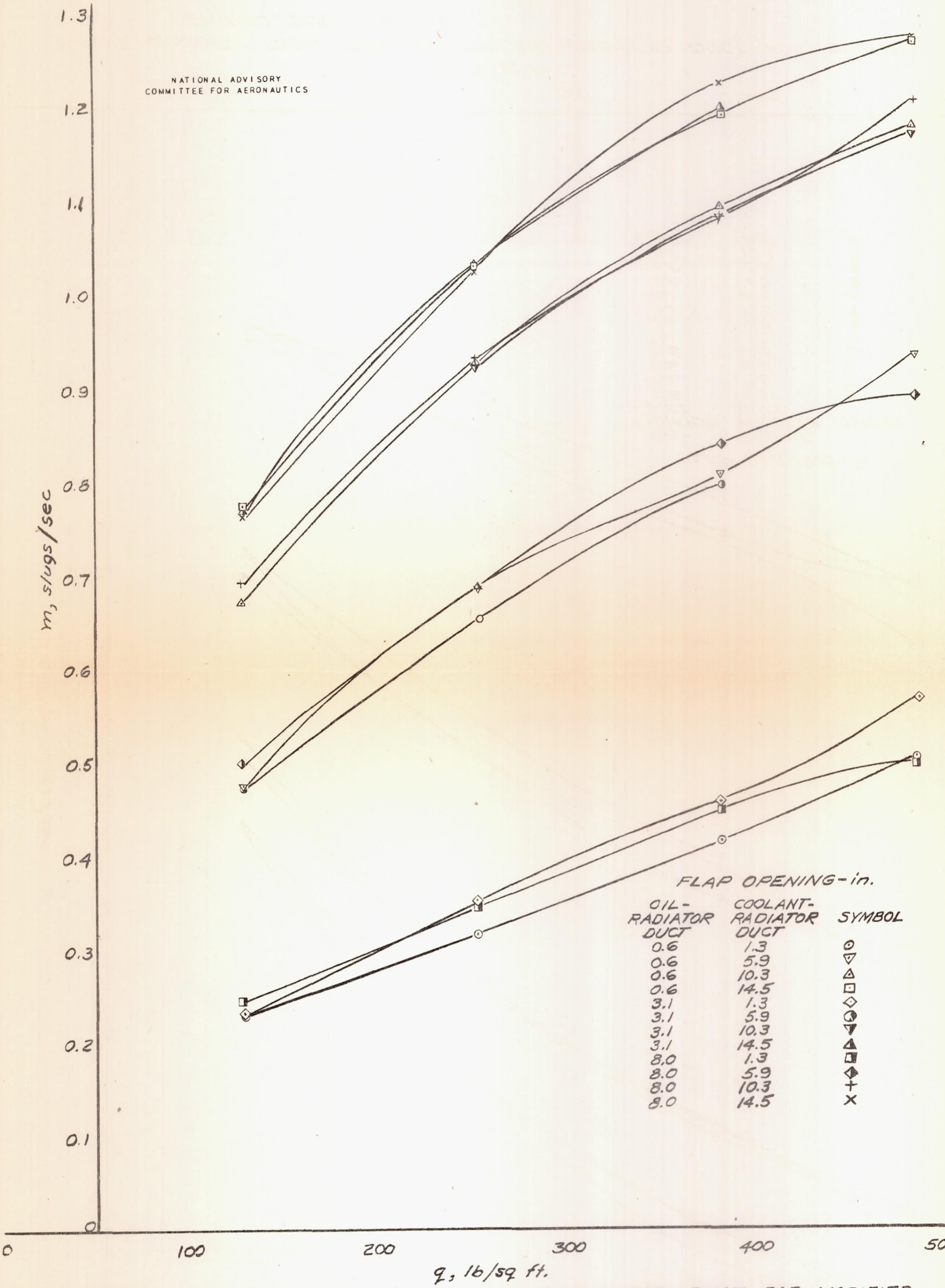

FIGURE 18.- MASS FLOW THROUGH COOLANT-RADIATOR DUCT FOR MODIFIED DIVIDED DUCT. $\alpha = -2°$

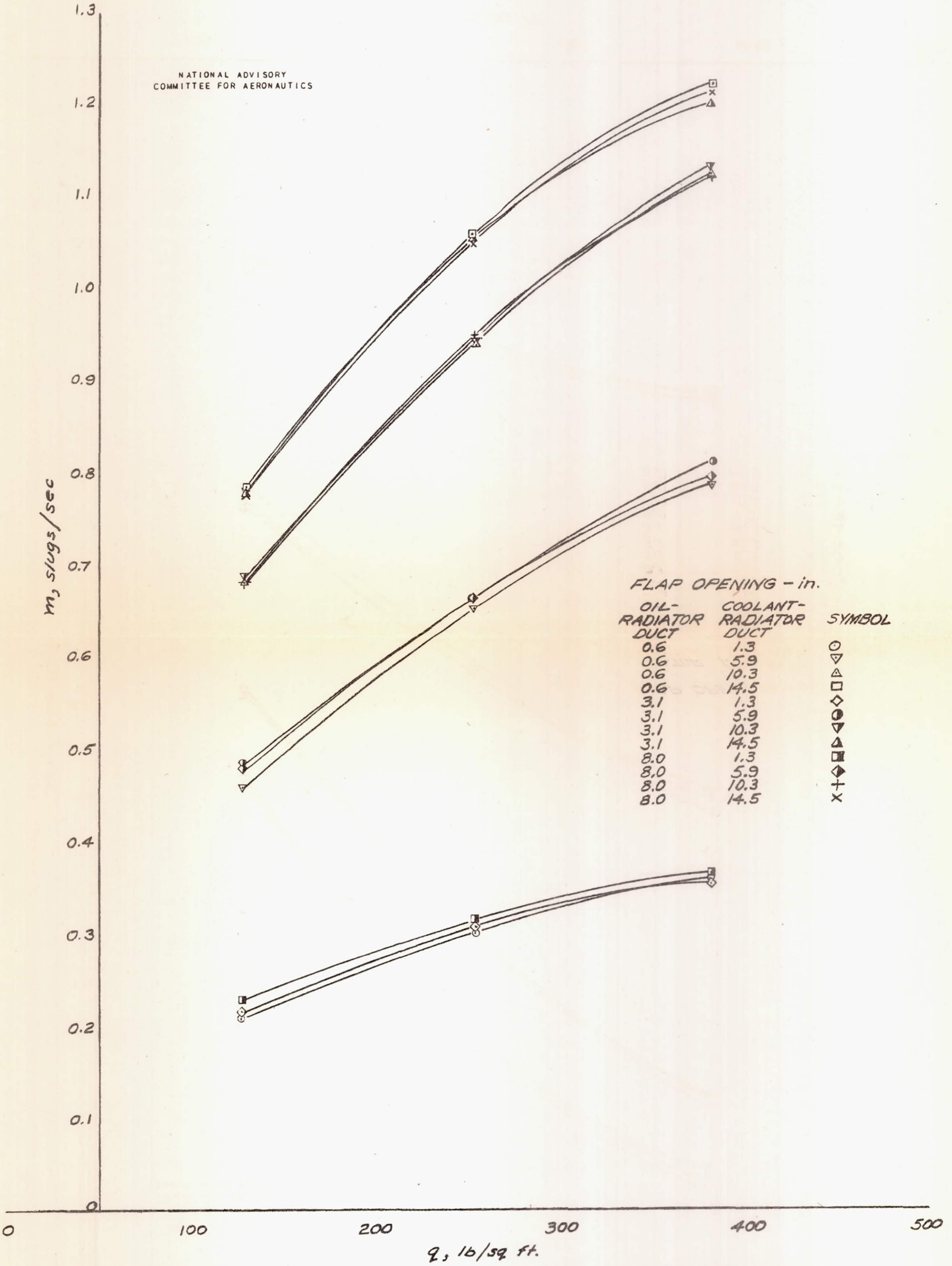

FIGURE 19.- MASS FLOW THROUGH COOLANT-RADIATOR DUCT FOR MODIFIED DIVIDED DUCT $\alpha = 0.56°$

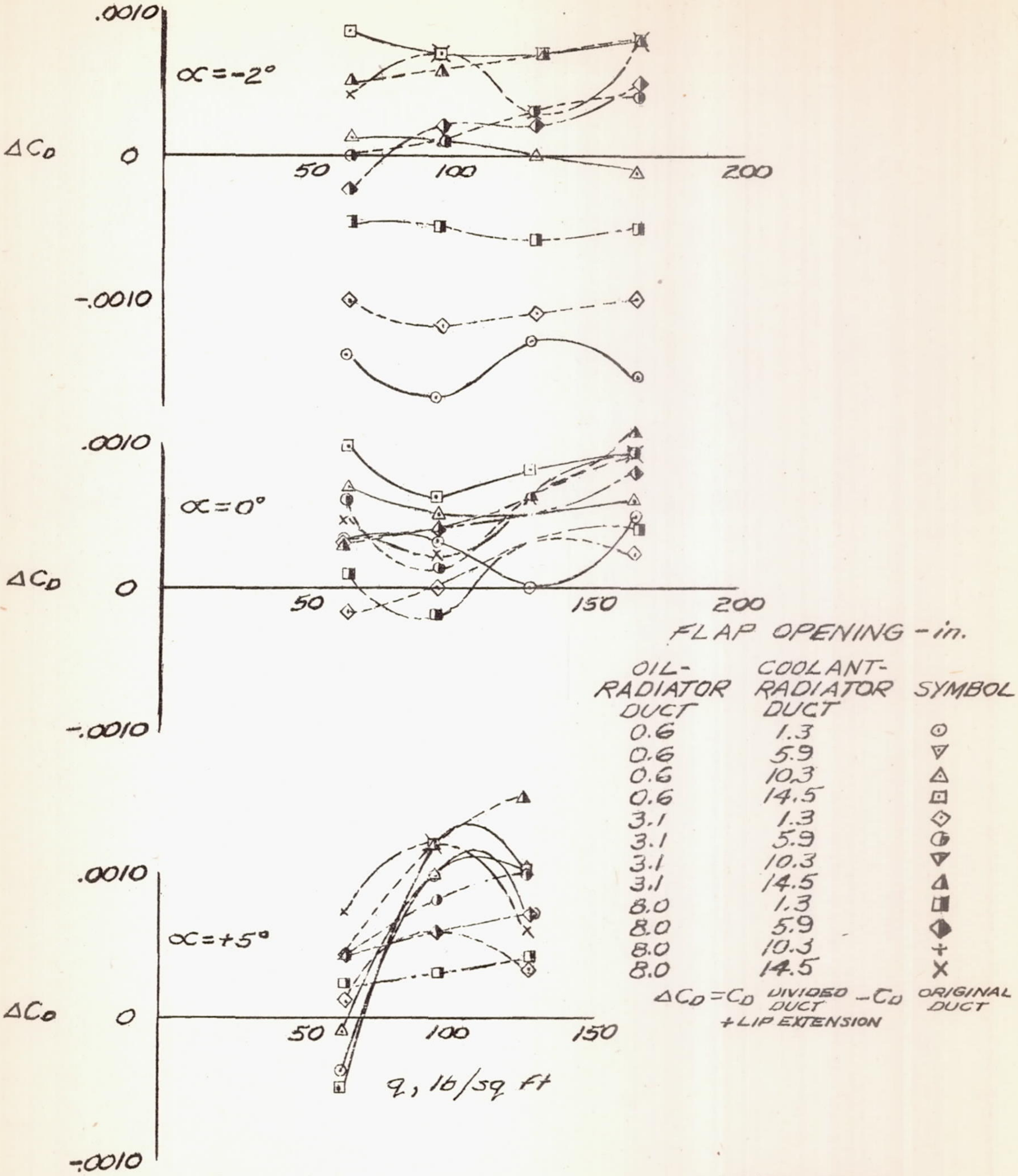

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FIGURE 20.- DRAG INCREMENT FOR DIVIDED DUCT WITH LIP EXTENSION.

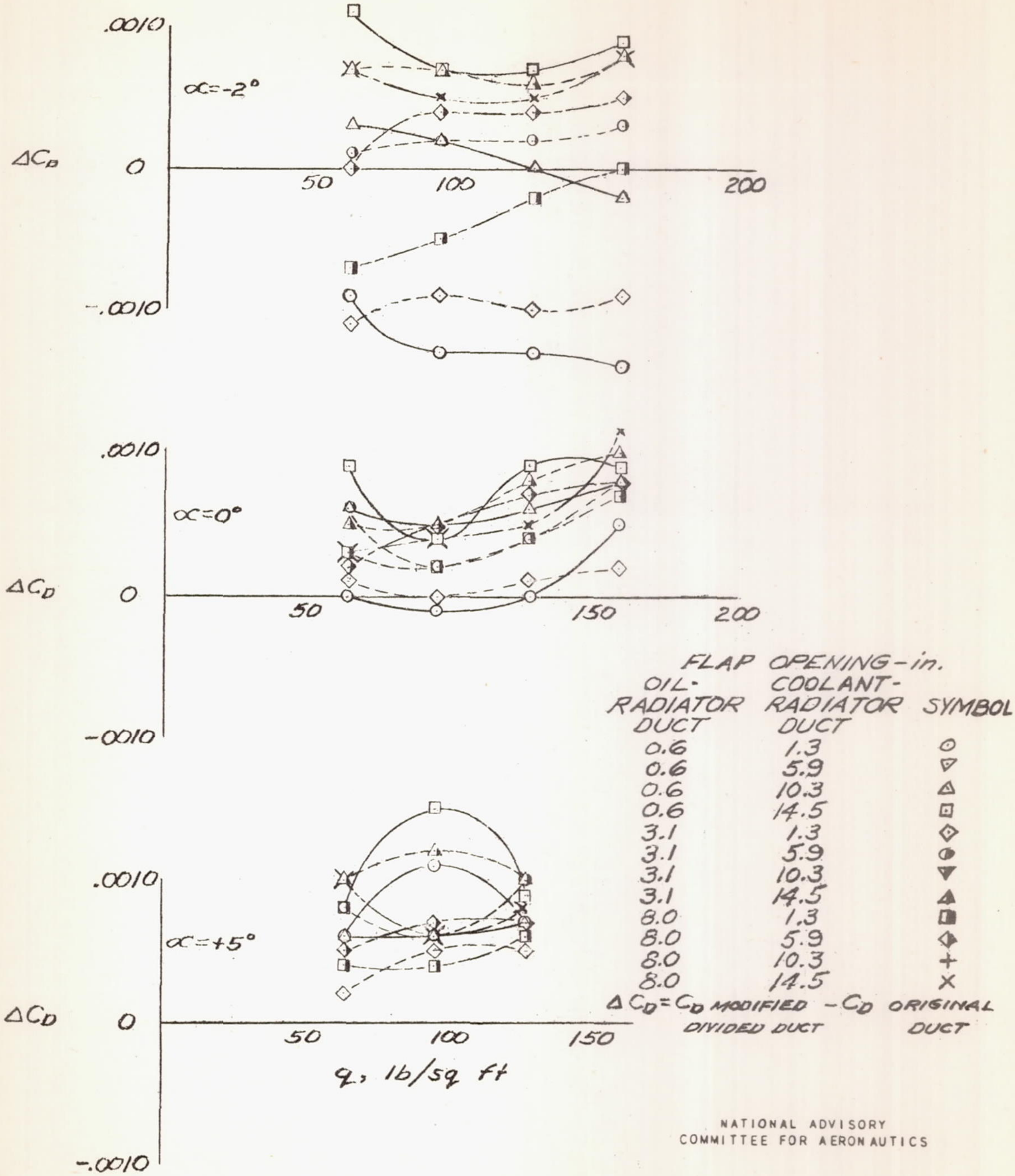

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FIGURE 21.- DRAG INCREMENT FOR MODIFIED DIVIDED DUCT

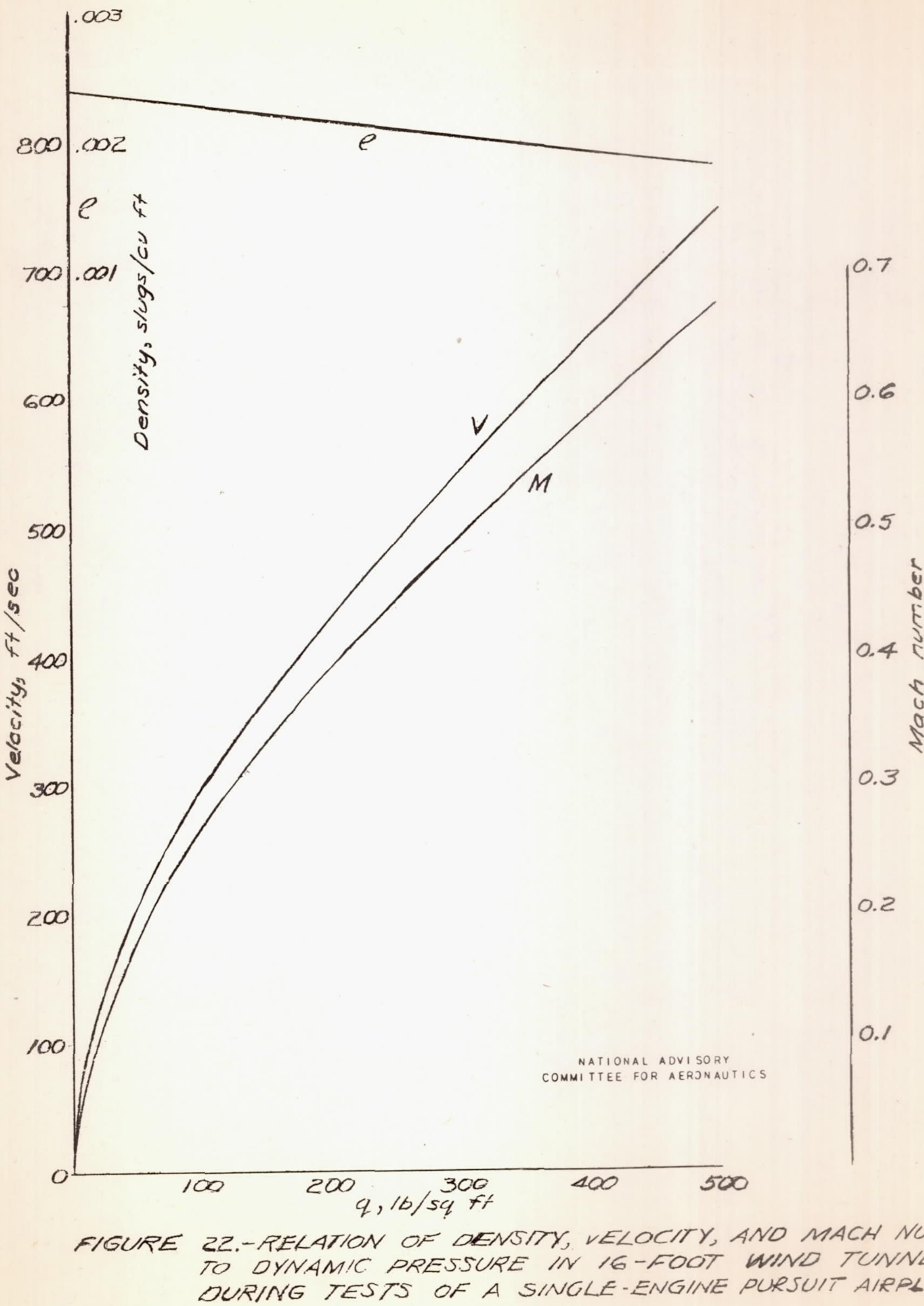


FIGURE 22.- RELATION OF DENSITY, VELOCITY, AND MACH NUMBER TO DYNAMIC PRESSURE IN 16-FOOT WIND TUNNEL DURING TESTS OF A SINGLE-ENGINE PURSUIT AIRPLANE.

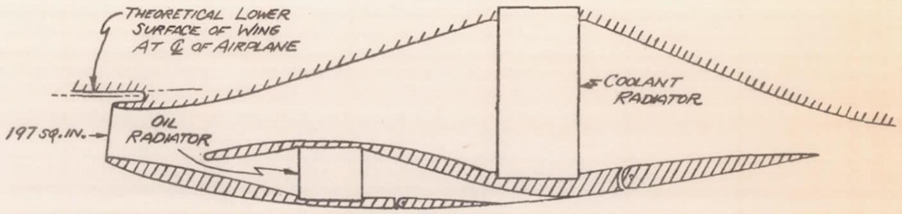
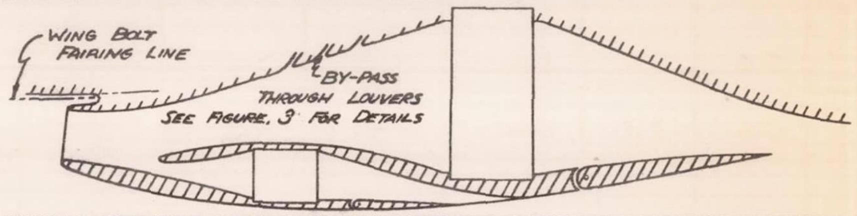
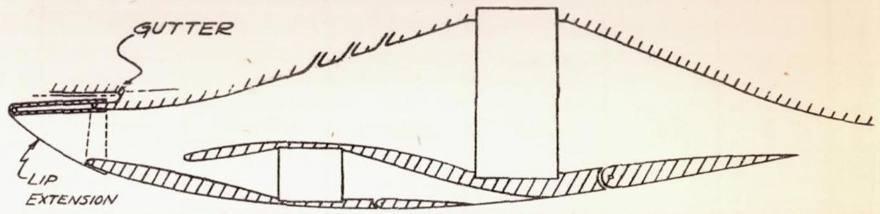
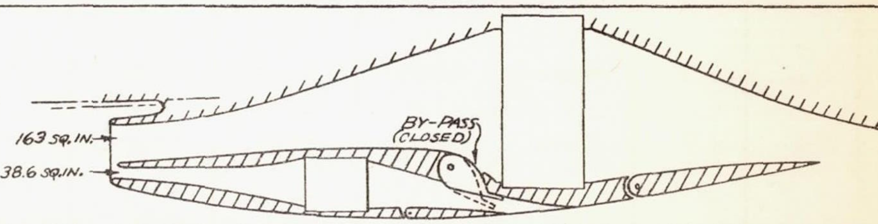
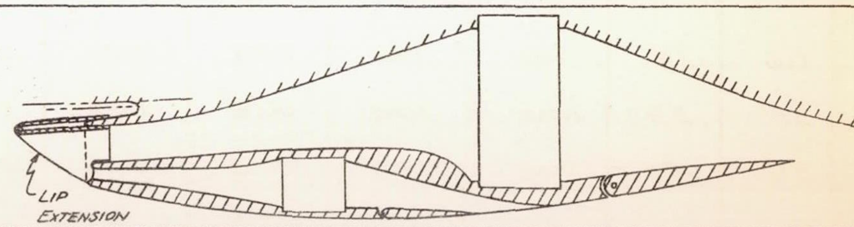
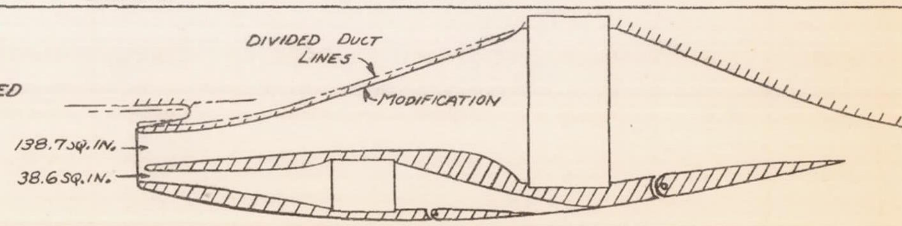
Duct	Flap Opening - Inches		Rumble $\alpha = -2°$		ΔC_D ($C_D - C_D$ with original duct) Wing Area = 233.19 sq. ft. $\alpha = 0°$		Mass Flow Slugs per Second $q = 385$ lb/sq. ft. $V = 430$ M.P.H. Mach No. = .570 $\alpha = -2°$	
	Oil	Coolant	$q = 254$ lb/sq. ft. V = 337 M.P.H. Mach No. = .446	$q = 487$ lb/sq. ft. V = 500 M.P.H. Mach No. = .665	$q = 63$ lb/sq. ft. V = 161.5 M.P.H. Mach No. = .208	$q = 127$ lb/sq. ft. V = 230.5 M.P.H. Mach No. = .305	Oil Radiator Duct	Coolant Radiator Duct
Original Duct 	0.6	1.3	Severe	—	—	—	0.107	0.650
	0.6	5.6	Starts	—	—	—	—	—
Original with By-Pass 	0.6	1.3	Heavy	—	—	—	—	—
	0.6	3.5	Starts	—	—	—	—	—
Original with By-Pass and Lip Extension 	0.6	1.3	Slight	Medium	—	—	—	—
	0.6	5.6	None	Starts	—	—	—	—
Divided Duct 	0.6	1.3	Medium	Heavy	—	—	—	—
	0.6	1.9	Starts	—	—	—	—	—
Divided Duct with Lip Extension 	0.6	1.3	None	None	.0003	.0000	0.103	0.520
	3.1	5.9	None	None	.0006	.0006	0.237	0.778
	8.0	14.5	None	None	.0005	.0006	0.306	1.250
Modified Divided Duct 	0.6	1.3	None	None	.0000	.0000	0.093	0.412
	3.1	5.9	None	None	.0006	.0004	0.244	0.796
	8.0	14.5	None	None	.0003	.0005	0.299	1.220

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Figure 23.- Duct designs and summary of their performances